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Smoke control in single-storey shopping malls

Should a fire occur in a shop in a covered shopping centre, people escaping along malls may become enveloped in thick smoke. A glass shop front is not a reliable barrier to the flow of hot smoky gases on to the mall because it may break early in the fire.

It is therefore necessary to restrict the travel of smoke either within the shop or within a short length of the mall. The measures necessary to achieve this in single-storey or horizontally-compartmented shops or malls are described in this digest.

When a fire occurs

A column of hot gases and flames rising above a fire draws in or entrains surrounding air (Fig 1). The entrained air becomes contaminated with smoke and other combustion products, which may be toxic, and its temperature is raised. The resulting gases spread out to form a layer beneath the ceiling.

If the fire occurs in an open-fronted shop in a mall, the hot smoky gases will start to flow out beneath the fascia as soon as they reach it, unless there is a system for exhausting the gases from the shop. If the shop has a glass front, it must be assumed that this will break early in a fire to produce, in effect, an open-fronted shop.

The gases will flow out of the upper part of the shop front and rise to the ceiling of the mall while the air to replace them will flow in through the shop front at a lower level.

In the mall, the gases will form a layer beneath the ceiling; this layer will flow faster than the rate of flow from the shop because its volume is increased by the entrainment of air as the gases flow out of the shop front and for some distance along the mall. The layer of hot gases will advance along the mall by the pressures resulting from the buoyancy of the hot gases.

At the same time, air is drawn into the shop on fire (Fig 2) so that there will be a flow of air along the lower part of the mall towards the fire. At first, this air will be free from smoke and the hot smoky layer will probably occupy no more than the upper third of the mall. If the mall is high enough, the smoke layer will be well above people's heads and escape will not be impeded by smoke. But some mixing between the two flows does occur; a relatively stagnant smoky layer forms between the layer of hot gases flowing away from the fire and the return flow of fresh air (Fig 3) and some smoke from this layer mixes into the return air flow which thus gets progressively more smoky. When the hot, smoky upper layer reaches the end of the mall, further mixing occurs. At an open end, the hot gases flow out of the top part and fresh air flows in beneath them, but even a slight breeze will cause sufficient turbulence to mix the smoke with the return air flow, and the mall becomes filled with smoke in the vicinity of the open end— which is usually the exit. At a closed end, or at an obstruction, the layer virtually doubles in depth and mixing of smoke into the return air flow increases along the length of the mall. The mall becomes more thickly filled with smoke moving at pedestrian height from the closed end or obstruction, back towards the fire (Fig 4). This general flow of smoke towards the fire could easily mislead people about the location of the fire and the best direction in which to escape.

Fig 1 Entrainment of air into flames and hot gases rising from fire

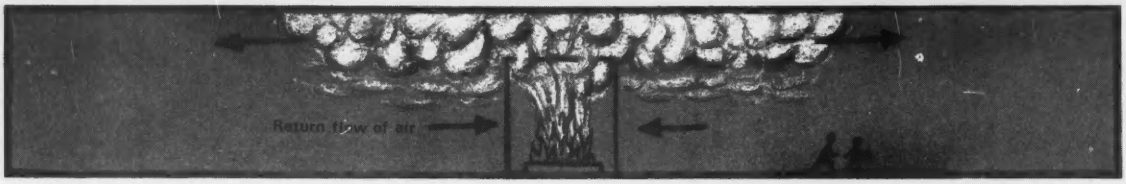

Fig 2 Hot gas layer spreading along the mall

How fast does this happen?

When the fire has attained a moderate size, with flames approaching the ceiling, the smoke will take only a few seconds to fill the space beneath the ceiling of the shop before starting to flow out into the mall. It has been calculated that a fire of 3 m x 3 m in plan area, in a 1000 m^3 shop 5 m high, would fill the upper 2 m of the shop with smoke and hot gases in about one minute.

In the mall, the layer of hot gases will advance at a rate of about 1 m/s if the fire is being held in check by sprinklers. If the fire is unchecked, the rate of advance will be higher; in one instance, it is likely that a mall 100 m long became untenable because of heat and smoke in less than one minute.

1 m/s is only a slow walking pace if progress is unimpeded; but congested crowds move even more slowly and the rate of flow on escape routes may be only about 0.5 m/s. Congestion is likely near exits which are frequently at the ends of malls; here, in the absence of smoke-control measures, the smoke becomes thick at ground level before it does so further inside the mall. People may emerge from shops at a time when a layer of smoke is above their heads and the exits are clearly visible, only to find that the end of the mall is filled with smoke before they can reach it.

Design measures

Four measures are needed to cope with this potential situation:

1 Install a sprinkler system in each shop to limit the size of a fire and the amount of smoke produced.
2 Form smoke reservoirs below the ceilings.
3 Extract the smoke from these reservoirs.
4 Provide for the entry of replacement air.

All four of these provisions must be made; none will be effective on its own. The system may be used to confine the smoke to the shop of origin but for this to be effective it is necessary to ensure that the shop front will retain its integrity during a fire, ie glass front not to fall out, self-closing fire doors with adequate seals and, possibly, pressurising the mall relative to the shop. It is therefore more usual to design a system that will limit the spread of fire and smoke in the malls, though it is also desirable to ventilate the smoke from large shops.

To minimise apprehension and reduce the possibility of panic, the bottom of the layer of hot smoky gases in a mall should be as high as possible above people's heads. A height of 2.5 m for the bottom of the gas layer is probably the absolute minimum; dense smoke is generally confined to the upper third of the mall and hence the height of a mall should not be less than about 4 m.

Sprinklers

It is seldom practicable, for economic reasons, to design a smoke-control system for a shopping centre that will exhaust the hot gases from a fire of more than limited size. Reliance will generally be placed on sprinklers to ensure that the fire does not exceed the design size.

Sprinkler discharge in a shop will greatly increase the amount of mixing of smoke and air, so that the shop may fill with swirling smoke down to floor level. The smoke will, however, flow out of the upper part of an open shop front and air will flow in through the lower part in the same manner as with an unsprinklered fire. In operation, sprinklers will not impair natural venting and will increase the effectiveness of a mechanical extraction system.

Sprinklers are not desirable in a mall because of their effect on smoke movement, but if the mall is to

Fig 3 Formation of stagnant layer of smoke

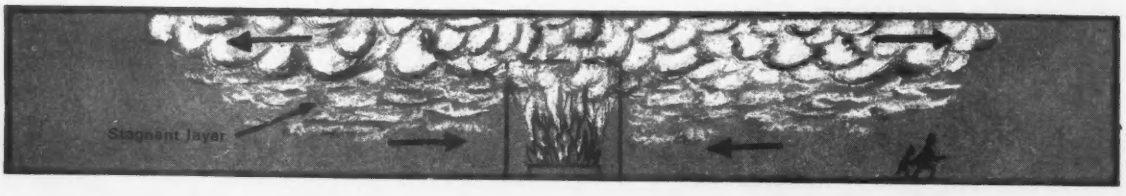

Fig 4 Smoke flow back along the mall

be used for displays or exhibitions which are likely to provide combustible materials, it must have the same measure of protection as the rest of the complex, ie sprinklers must be fitted.

Any smoke-control measure which requires functioning of fans, ventilation, screens, doors, etc should come into operation automatically at the earliest possible stage. By the time a fire has become large enough to actuate a fusible link, it is likely to be producing a very considerable volume of hot smoky gases. Fusible links in the mall are incapable of reacting early enough to a fire in a shop. Smoke detectors are a suitable means of activating smoke-control devices; if the system is intended to restrict gases to the shop of origin, the detectors must generally be situated in the individual shops.

Smoke reservoirs

To help control movement of the layer of gases below the ceiling, smoke reservoirs should be formed to a depth of about one-third of the storey height. If the ceiling of the mall is higher than that of the shops, the difference in levels may be of sufficient depth for these reservoirs (Fig 5a), but if the difference is not sufficient, deep fascias will be needed above the shop fronts (Fig 5b). To limit the distance of smoke travel along the mall, the reservoirs should be no more than about 60 m long and dividing screens might therefore be needed. Within a shop, a reservoir can be formed by the enclosing walls and a deep fascia over the shopfront. The area of a smoke reservoir should not exceed 1000 m^2 to avoid cooling the layer to an extent that would reduce the efficiency of smoke extraction; screens may be needed to sub-divide the area of a larger shop.

Ceiling screens must be continued up through the space above a suspended ceiling, unless the latter is fire-resisting and sufficiently airtight to prevent smoke leakage. If a suspended ceiling is of an open type of construction, and forms a sufficiently deep space, the smoke reservoirs may be confined entirely to this space and dividing screens need not extend below it.

Smoke extraction from reservoirs

The hot smoky gases must be extracted from the smoke reservoirs either by natural or mechanical ventilation. Extract rates and estimates of the maximum gas temperatures which the extract system must withstand are given in Table 1. These are based on a fire covering a floor area of 3 m x 3 m with a heat output of 5 MW, which is considered reasonable for a fire that is controlled by sprinklers. The estimates neglect the cooling of the hot gases by heat loss to the ceiling and by radiation downwards, so that temperatures a long way from the fire will be somewhat lower. This cooling is advantageous with a mechanical extract system but can reduce the efficiency of a natural system. Temperatures will be higher than those stated if the heat output of the fire exceeds 5 MW, as it may if a sprinkler head fails to open properly.

Table 1 Rates of extract required from smoke reservoirs

Height of lower edge of screen	Mass rate of extract		Max temp of hot gases above ambient		Extract rate (at max temp)	
	shop	mall	shop	mall	shop	mall
m	kg/s	kg/s	°C	°C	m^3/s	m^3/s
2.5	9	18	560	280	22	29
3	12	24	420	210	24	34
3.5	15	30	340	170	26	39
4	18	36	280	140	29	44
5	25	50	200	100	35	56
6	35	70	150	75	44	73

The areas of vent necessary to exhaust the gases are given in Table 2. These assume that the temperature in the vicinity of the vents is at least 100°C above ambient; in practice, some cooling occurs, particularly with large area reservoirs, and the

Fig 5a

Fig 5b

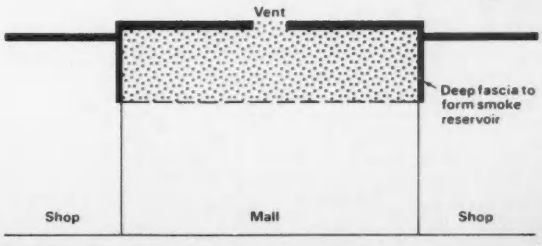

Table 2 Minimum areas of vent (m^2) to smoke reservoirs in single storey malls (For smoke reservoirs in shops, halve the areas given below)

Height of lower edge of screen	Height of outlet above lower edge of screen (m)					
m	1.5	2	3	5	8	10
2.5	10	9	7	6	4	4
3	13	12	9	7	6	5
3.5		15	12	9	7	6
4		18	14	11	9	8
5			20	16	12	11
6			26	21	16	15

Note: Generally, areas should be $1^1/_2$ per cent of floor area in large shops or 3 per cent of floor area in small shops, but not less than the figures given in the above table.

areas should be regarded as minimum ones. Because of the difficulty of estimating the temperature of the gas layer, a rule-of-thumb is frequently adopted; in a single-storey mall where the lower edges of screens are not more than 3.5 m above the floor, the total area of vent should be 3 per cent of the floor area; in large shops, the total area of vent should be $1^1/_2$ per cent of the floor area.

The area of vent in a single smoke reservoir should be not less than is given in Table 2. This area should be divided between a number of outlets, uniformly distributed, in accordance with Table 3 which is based on a temperature of 100°C for the gas layer. Smoke outlets should be sited at the highest possible position in the reservoir, away from walls and other obstructions to flow.

Fresh air inlets

Inlets must be provided for fresh air to enter the building. Although this is sometimes said to be undesirable because it might promote a faster rate of burning, it is essential if smoke is to be extracted and the escape of people facilitated.

With a natural ventilation system, the area of the inlets should be at least twice the area of the vents in any single smoke reservoir. A smaller inlet area may be sufficient with a mechanical system.

Doors in the ends of malls are suitable inlets if it can be ensured that they will be opened in the event of a fire. Fresh air flowing along the malls from end doors will reduce the likelihood of smoke flowing out of the smoke reservoirs but a disadvantage of using end doors is the mixing that occurs at the end of the mall with even a slight wind. The effect of this can be minimised by placing a smoke screen several metres inside the mall.

Other possible inlets are windows or ventilators at the rear of shops, or vents in smoke reservoirs remote from the fire, but the method adopted should not induce mixing between the layer of hot smoky gases and the air beneath. A mechanical ventilation system might be capable of supplying at least some of the required air but inlet grilles must be designed and located so that they do not cause the smoke to mix with the fresh air flow. If air is admitted through ceiling grilles, it may be necessary to shut off the mechanical inlet ventilation in the event of fire.

Table 3 Minimum number of outlets from a single smoke reservoir in a mall (For extraction from shops, halve the numbers given below)

Height of lower edge of screen	Depth of reservoir (m)						
m	1	1.5	2	2.5	3	3.5	4
2.5	9	4	2	1	1	1	1
3	12	4	2	2	1	1	1
3.5	15	6	3	2	1	1	1
4	18	7	3	2	2	1	1
5	24	9	4	3	2	2	1
6	34	12	6	4	3	2	1

Advice

It is essential that smoke control measures should be considered at an early stage in the design of the building complex, since they may be difficult to incorporate as an afterthought. Developments of the kind described present particular problems in relation to the Building Regulations and advice should be sought, at the design stage, from the local authorities, the Building Regulations Division of the Department of the Environment, and the local fire authority.

Further reading

HINKLEY P L *Some notes on the control of smoke in enclosed shopping centres* Fire Research Note No 875/1971

SPRATT D and HESELDEN A J M *Efficient extraction of smoke from a thin layer under a ceiling* Fire Research Note No 1001/1974

Fire Prevention Guide No 1 *Fire precautions in town centre redevelopment* Home Office and Scottish Home and Health Department. London HMSO (1972)

Department of the Environment **Building Research Establishment**

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